A POSSIBLE SUBMARINE MUD VOLCANO FROM THE SOUTHEAST BAFFIN ISLAND SHELF

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ABSTRACT

This paper describes a seabed feature interpreted as a mud volcano which occurs on the southeast Baffin Island Shelf in about 230 m of water. The morphology of the mud volcano is described from four independent sets of remotely sensed geophysical data and its location above a major geological contact is shown. The mechanism of formulation may be by the extrusion of a pressurized mixture of unconsolidated sediments, oil, gas and conate water escaping to the seafloor by upward movement along a contact between Tertiary and Precambrian rocks. This may occur during periods of earthquake activity. The age of the volcano is not known but evidence suggests it may be a recent feature.

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TABLE OF CONTENTS

	Page
ABSTRACT	i
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	v
LIST OF FIGURES	vii
INTRODUCTION	1
Scope of Work	1
Regional Geology	1
Oil Seep	8
Tectonic Activity	9
Survey Methods	13
Results	13
Interpretation	27
CONCLUSIONS	31
REFERENCES	33

LIST OF FIGURES

	Page
Figure 1 - Location map of mud volcano ----------	3
Figure 2 - Airgun record showing bedrock geology and mud volcano ----------	5
Figure 3 - Huntec record showing mud volcano --------	7
Figure 4 - Map showing recent earthquake epicentres -	11
Figure 5 - Echosounder records of the cone showing: a) conical shape b) asymmetric flanks c) possible vent on the summit ----------	15
Figure 6 - Track plot of the 1982 relocation survey -	19
Figure 7 - Bathymetric map of the mud volcano showing sample locations ----------	21
Figure 8 - Three-dimensional display of the bathymetry viewed at an angle of 45° from the south-east ----------	23
Figure 9 - Sidescan record showing elliptical shape of mud volcano ----------	25

INTRODUCTION

Scope of Work

This paper describes a possible mud volcano discovered on the seafloor on the southeastern portion of the Baffin Island shelf (Fig. 1). The morphology of the cone and the surficial and bedrock geology with which it is associated are described and discussed. A brief overview of previous work on mud volcanoes and mechanisms of mud volcanism is presented and some tentative conclusions are drawn regarding the mechanism of formation and the relative age of the described volcano.

Regional Geology

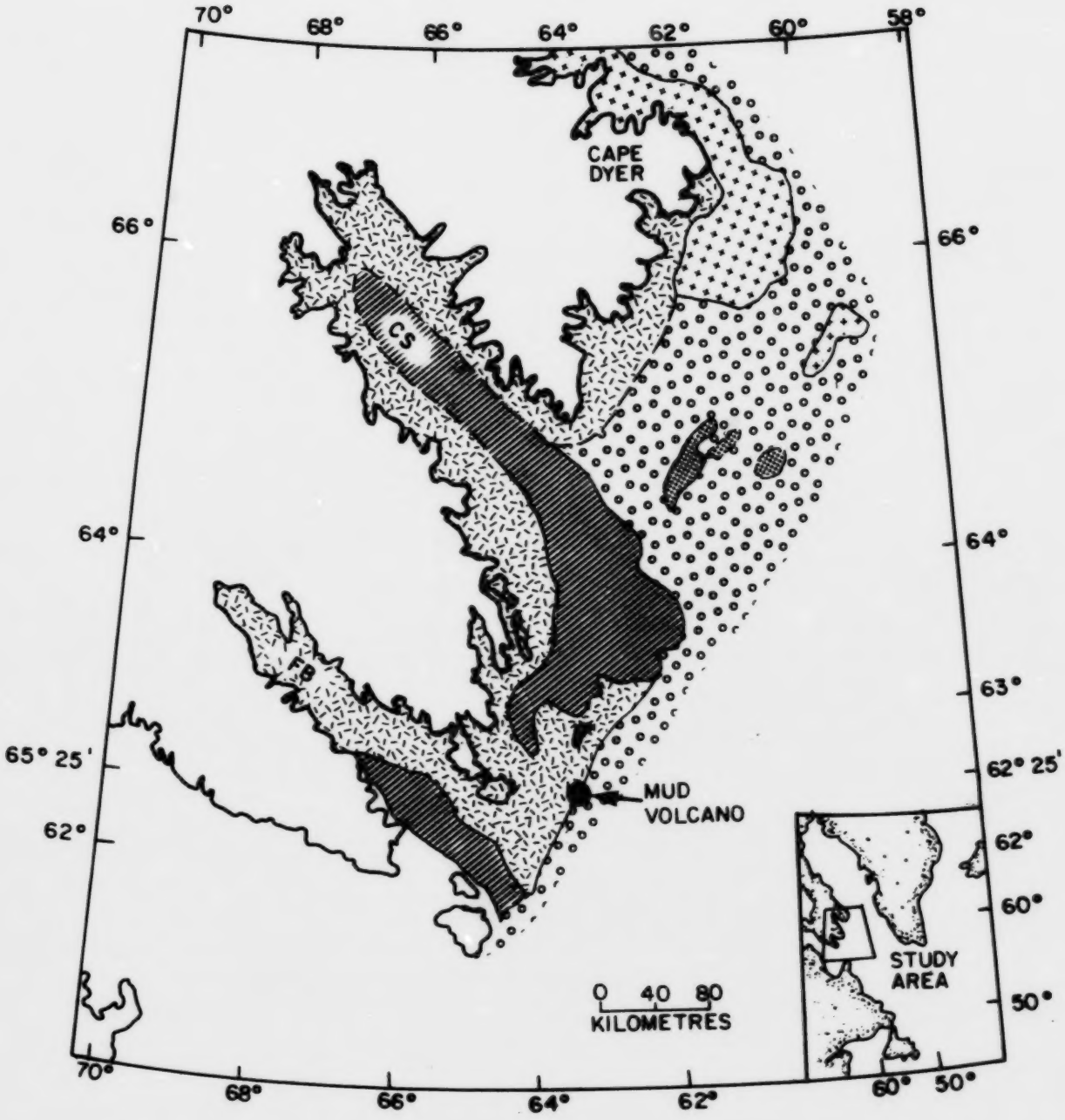
Grant (1975), in describing the bedrock geology of the Frobisher Bay area, noted that an outlier of Lower Paleozoic rocks in Frobisher Bay, previously mapped by Grant and Manchester (1970), extended seawards to a major fault separating it from rocks of Cretaceous - Tertiary age. MacLean and Falconer (1979) redefined the seaward extent of the outlier, interpreting the rocks southeast of Loks Land to be of Precambrian age (Fig.1). On their geology map they did not indicate the contact between Tertiary and Precambrian rocks as a fault.

Airgun data (Fig.2) clearly shows the Tertiary/Precambrian contact as a well-defined surface that dips eastwards at about 5°. The contact has a morphological expression on the seabed which shows up on both the airgun and Huntec (Fig.3) records as a shallow asymmetric depression about 1 km west of the cone.

Figure 1 - Location map of possible mud volcano. Geology after MacLean and Falconer (1979).

CS = Cumberland Sound

FB = Frobisher Bay



LEGEND

- TERTIARY (MAINLY) SEDIMENTS
- TERTIARY VOLCANICS
- PRE-TERTIARY ? SEDIMENTS IN DIAPIRIC STRUCTURES
- ORDOVICIAN SEDIMENTS
- PRECAMBRIAN METAMORPHICS

Figure 2 - Airgun record showing mud volcano located above the Precambrian/Cenzoic contact.

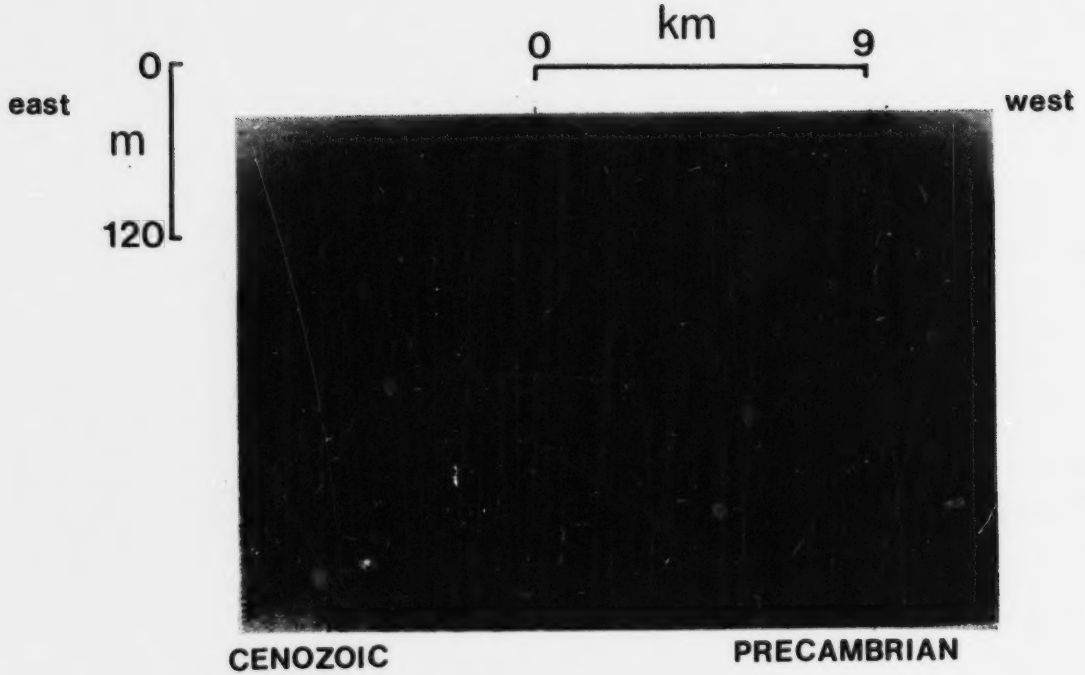
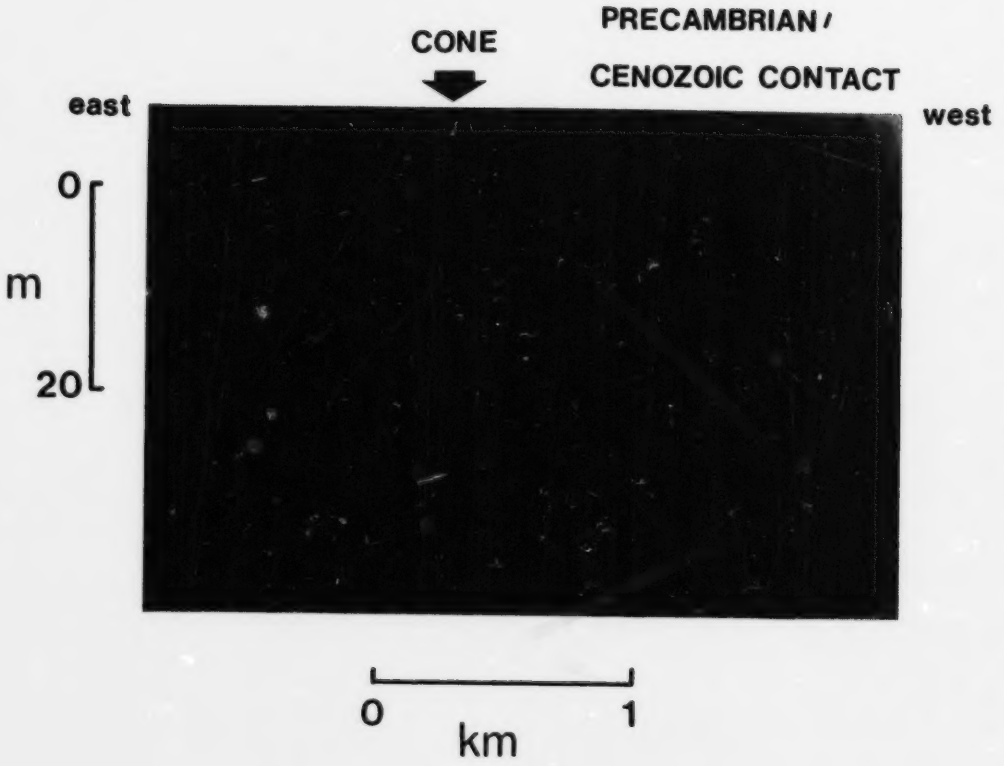

0
km
9
east
0
m
120
west
CENOZOIC
PRECAMBRIAN

Figure 3 - Huntec record showing smooth-sided mud volcano (conical feature), the Precambrian/Cenozoic contact (asymmetric depression) and scoured seabed.


CONE
PRECAMBRIAN /
CENOZOIC CONTACT
east
west
0
m
20
0
1
km

The Precambrian rocks are acoustically transparent and unlayered whilst the Cenozoic sediments consist of well-layered, gently east-dipping (1-2°) strata which pinch out at the contact with the Precambrian. Acoustic blanking of the Cenozoic/Precambrian boundary occurs at some depth below and slightly to the east of the mud volcano. This may be due either to gas-charged sediment along the contact, causing attenuation of the signal, or partial acoustic masking of the layering by the cone.

The sidescan record indicates a change in iceberg scour morphology across the contact. Scours on the seabed above the Cenozoic sediments are linear and curvilinear whereas scours above the Precambrian rocks are crater-like and discontinuous in form. The airgun record shows that the Precambrian rocks come close to the seabed indicating that there is a very thin veneer (probably 1-2m) of surficial sediment. It is likely that the change in scour morphology is related to this decrease in surficial sediment cover.

Oil Seep

Observations by Loncarevic and Falconer (1977), MacLean (1978), Levy (1978) and MacLean and Falconer (1979) have indicated the existence of perennial oil slicks offshore from Scott Inlet in northeast Baffin Island. Associated gas bubbles have been observed by Levy (1978) and MacLean (1978). The slicks occur above contacts between Precambrian and Tertiary/Pre-Tertiary (?) bedrock (MacLean and Falconer, 1979). Though the geology of Scott

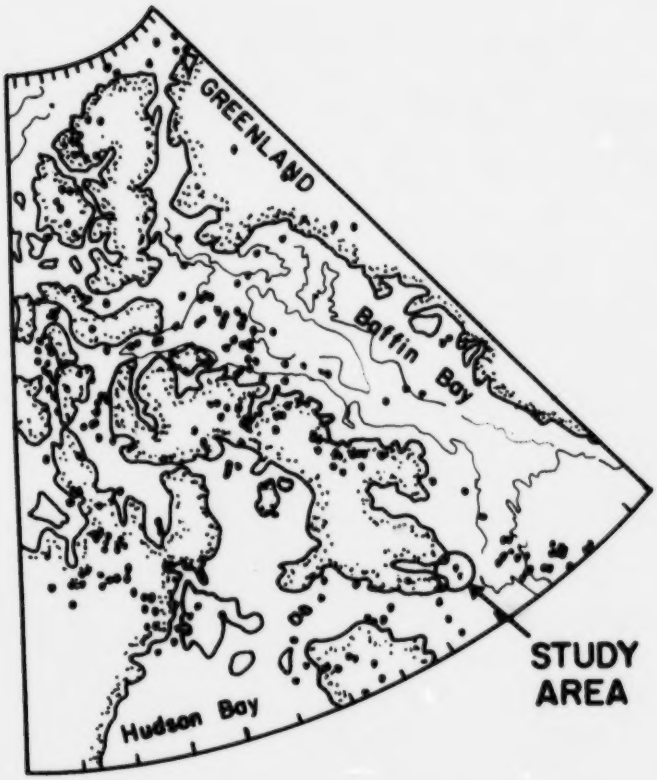
Inlet is more complex than in the Frobisher Bay area, the position on the continental shelf and nature of the contacts between the rocks and the rock ages are similar. Features that could be mud volcanoes have not been recognized in this region (MacLean, pers. comm.) although white colouration of the sediment has been observed on the seafloor at the points of oil extrusion (MacLean, 1982).

Sea level variations and maximum extent of the Quaternary Laurentide Ice Sheet in the area of southeast Baffin Island and adjacent continental shelf are not well known. However, it is fairly certain that the ice margin did not transgress beyond the eastern Baffin Island coast (Fillon et al., 1981). Isostatic uplift of southeast Baffin Island was underway by ca. 11,000 B.P. in response to the retreating Laurentide Ice (Miller et al., 1980). During this time, from ca. 18,000 B.P. to 5000 B.P., eustatic sea level was rising to present day levels and by 6000 B.P. up to 90% of southeast Baffin Island was exposed (Miller et al., 1980). There is no evidence, then, to suggest that the continental shelf was subaerially exposed in the study area.

Tectonic activity

Two earthquake epicentres, which may be associated with the Cenozoic/Precambrian contact (Fig. 4), have been recorded in the vicinity of the mud volcano (Wetmiller and Forsyth, 1978). The first occured on July 18th, 1962 and registered a magnitude of 4.9 on the Richter scale. The second was on June 15th, 1964 and showed a magnitude of 4.1 (pers. comm. R. Wetmiller).

Figure 4 - Map showing recent earthquake epicentres (from Wetmiller and Forsyth, 1978).


GREENLAND
Baffin Bay
STUDY AREA
Hudson Bay

Survey Methods

Data for this report were collected during cruise 81-045 of the Bedford Institute of Oceanography (BIO) research vessel **CSS HUDSON** in October 1981. The possible submarine mud volcano was located during a regional geological survey of the seabed in the vicinity of the Hekja O-71 wellsite drilled by Canterra Energy Ltd. in 1979 and in 1980 (Offshore, March 1982). Geophysical equipment used during the survey included:

i) a Huntec DTS (heave compensated) high resolution sub-bottom profiler (Hutchins et al., 1976);

ii) the BIO 70 khz sidescan sonar system (Jollymore, 1974);

iii) a 40 cubic inch airgun and

iv) a 12 khz echosounder (record not shown here).

During August 1982, additional surveying was undertaken from the rig supply vessel **M.V. FREEDOM SERVICE**, operated by Canterra Energy Ltd.; this involved relocating the mud volcano using an echosounder and retrieval of seven bottom samples. Analysis of these samples is not yet complete and will be the subject of a future report.

Results

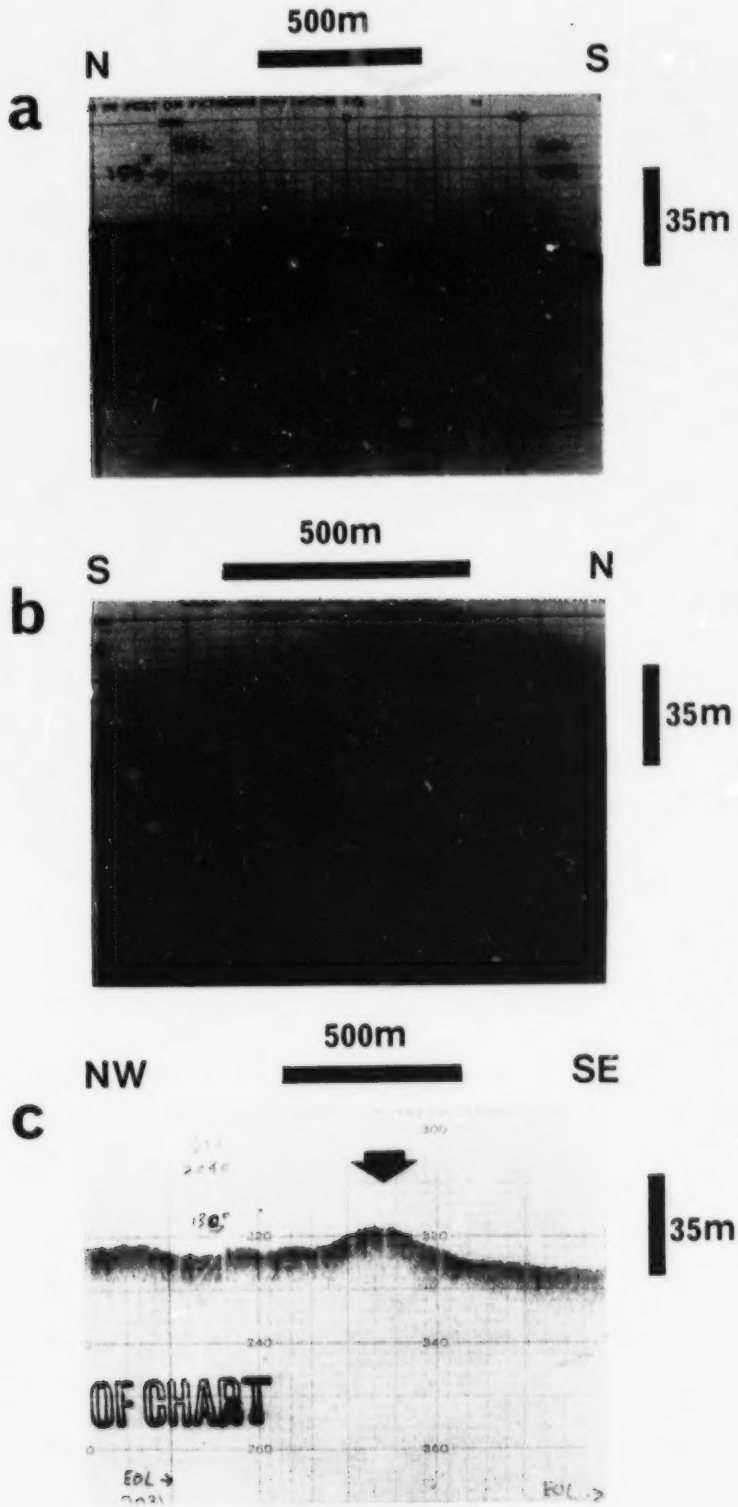
The cone is expressed on all four types of graphic displays in cross-section but is best seen on the Huntec record and on the August 1982 echosounder traces (Fig.5). The Huntec record shows a rough seabed which is characteristic of sediments that have been disrupted by iceberg scours. Iceberg scours in this region have penetration depths, measured from the seafloor, of about 2 m.

Figure 5 - Echosounder records of the cone showing:

a) conical shape

b) asymmetric flanks

c) possible vent below the summit


500m
N
S
a
35m
500m
S
N
b
35m
500m
NW
SE
c
35m
OF CHART

Though the quality of the Huntec record is not ideal due to noise problems, it can be seen that the surficial sediments are fairly compacted; there is little if any acoustic penetration. No coherent, near-surface reflectors can be seen.

The cone is displayed on the August 1982 echosounder traces as an asymmetric conical feature (Fig.5a) with a steep flank facing to the south (Fig.5b). A crater-like depression is apparent on the summit of the cone (Fig.5c). A total of six echosounder traverses were run over the area (Fig.6). From these records a bathymetric map was constructed to show the true shape of the cone (Fig.7). From this it is apparent that the crater is located approximately 40 m southwest of the cone summit. A computer surface mapping routine was also used to display the bathymetry in three dimensions (Fig.8).

The cone is about 12 m high and has a base diameter of about 600 m measured from the Huntec record. The flanks of the cone are slightly convex, becoming more so towards the summit, and the height to diameter ratio is about 1:50. The planimetric form of the cone was recorded on the sidescan sonogram (Fig.9) as a rather subdued elliptical feature. The long axis of the ellipse trends approximately north-northeast to south-southwest.

Although the seabed adjacent to the cone is severely affected by iceberg scours, it is important to notice that the cone itself is smooth-sided and unscoured. Both the sidescan and 1982 echosounder records clearly indicate that the flanks have not been affected by scouring icebergs.

Figure 6 - Track plot of the 1982 relocation survey. Small crosses mark the ship's position at approximately 100 m intervals and are the data points used to compile Figures 7 and 8.

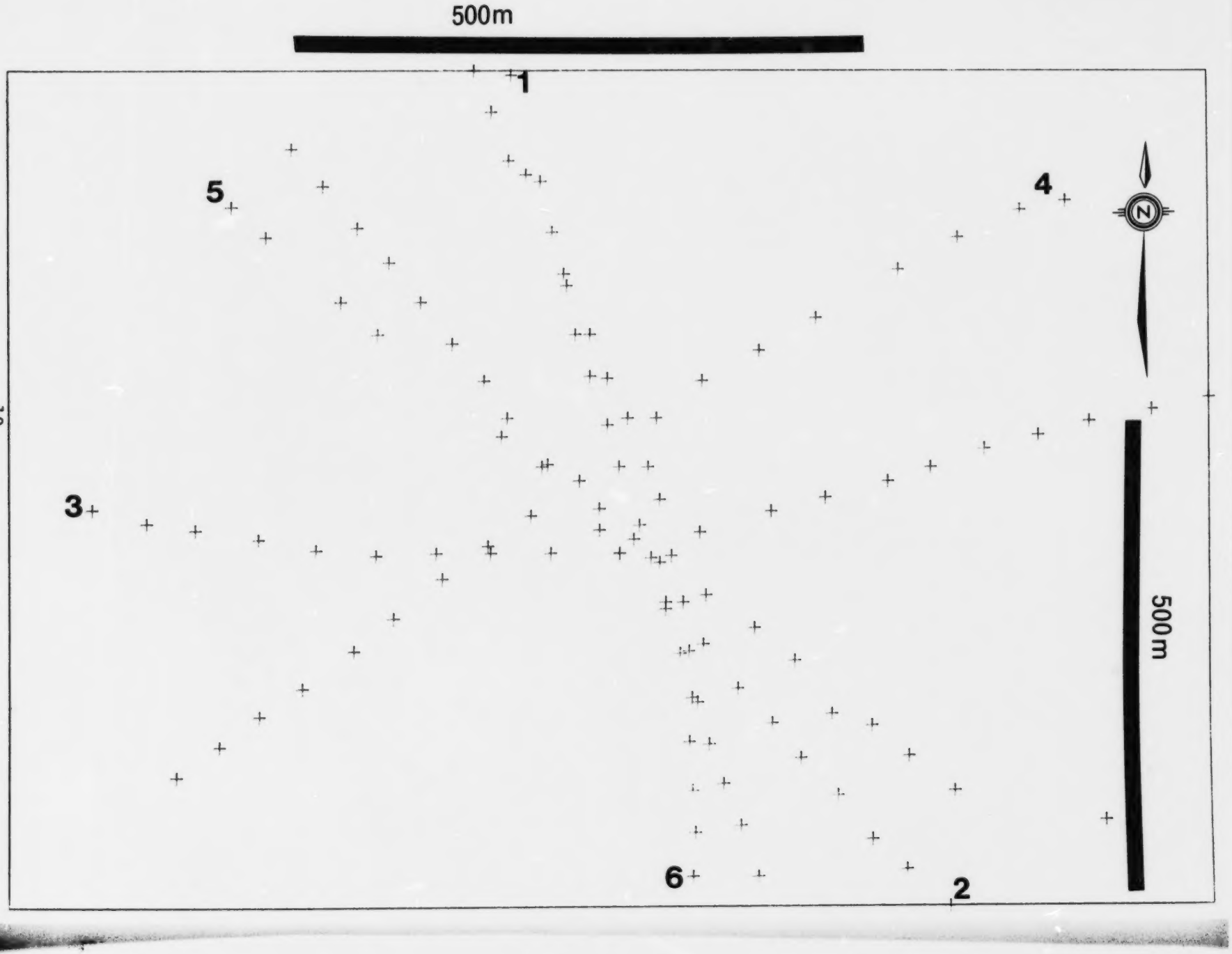

500m
1
2
3
4
5
6
N
500m
19

Figure 7 - Bathymetric map of the mud volcano showing sample locations (depth in metres).

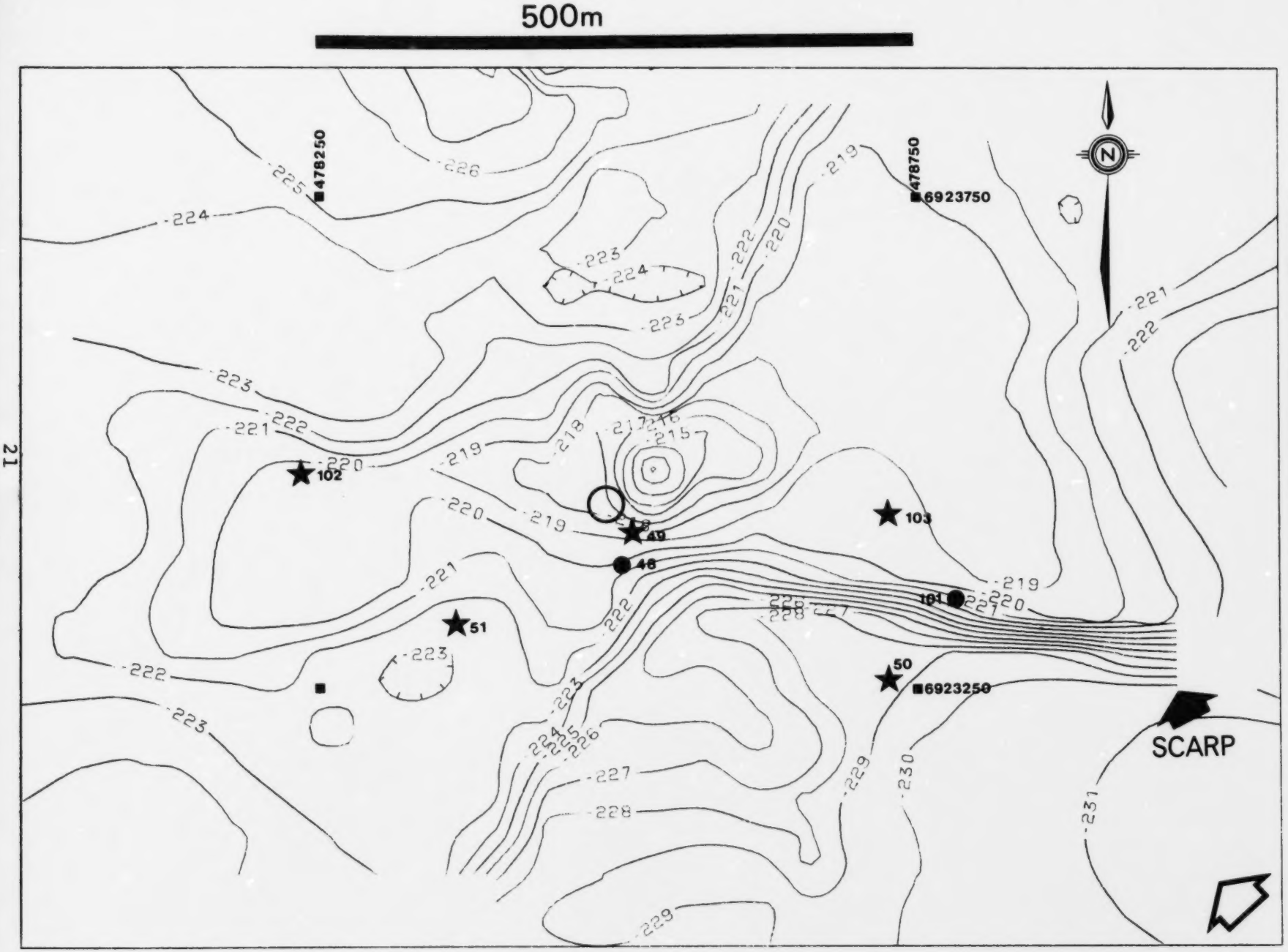
Black squares are Universal Transverse Mercator coordinates

Black dots are core samples

Black stars are grab samples

Open circle marks position of crater

Arrow in bottom right corner shows viewing direction of figure 8.


500m
500m
478250
478750
6923750
6923250
N
SCARP
102
103
49
46
101
51
50
225
226
224
223
222
221
220
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218
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227
228
229
230
231

Figure 8 - Three dimensional display of the bathymetry viewed at an angle of 45° from the southeast. Arrow marks summit of cone.

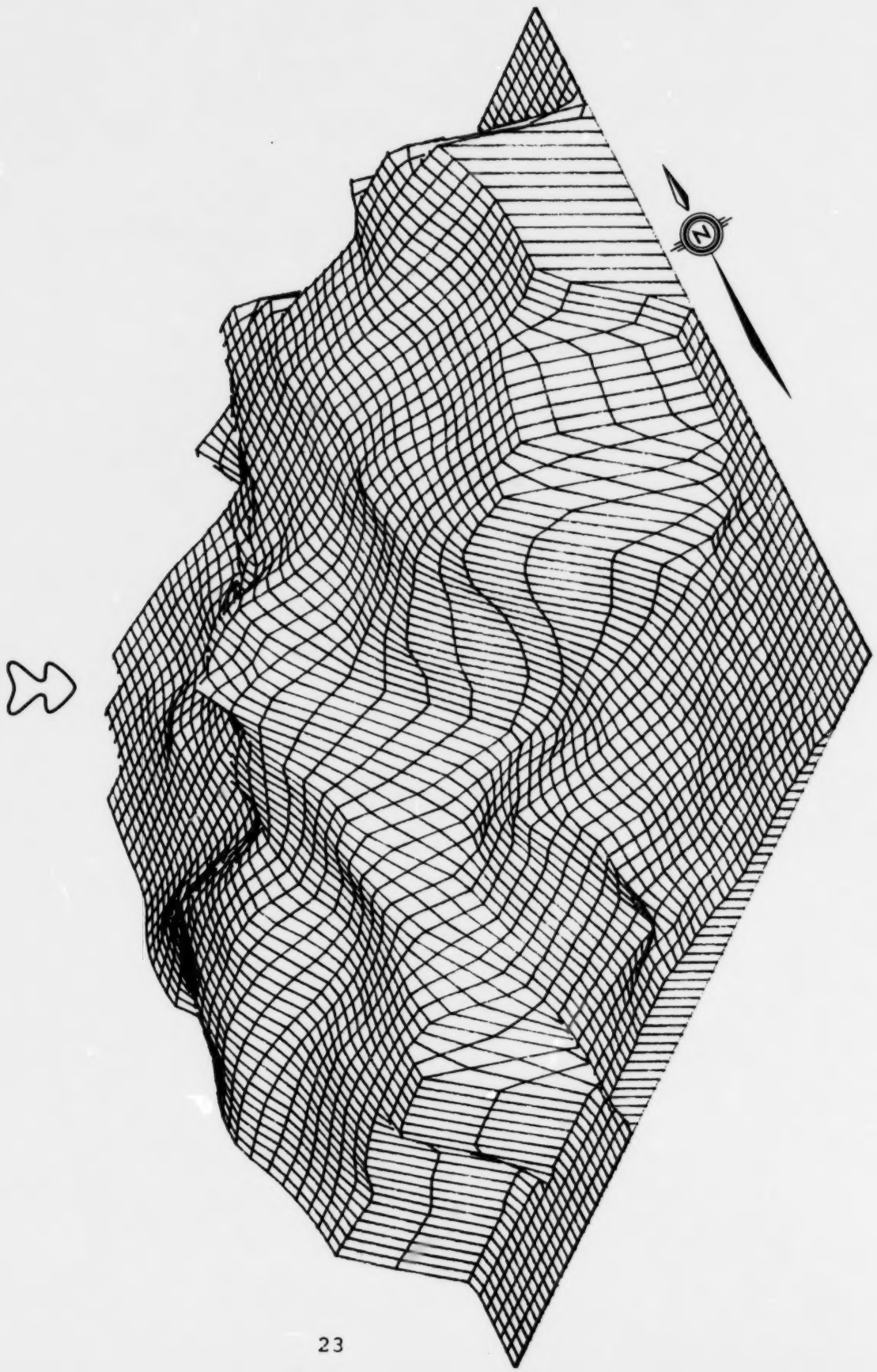
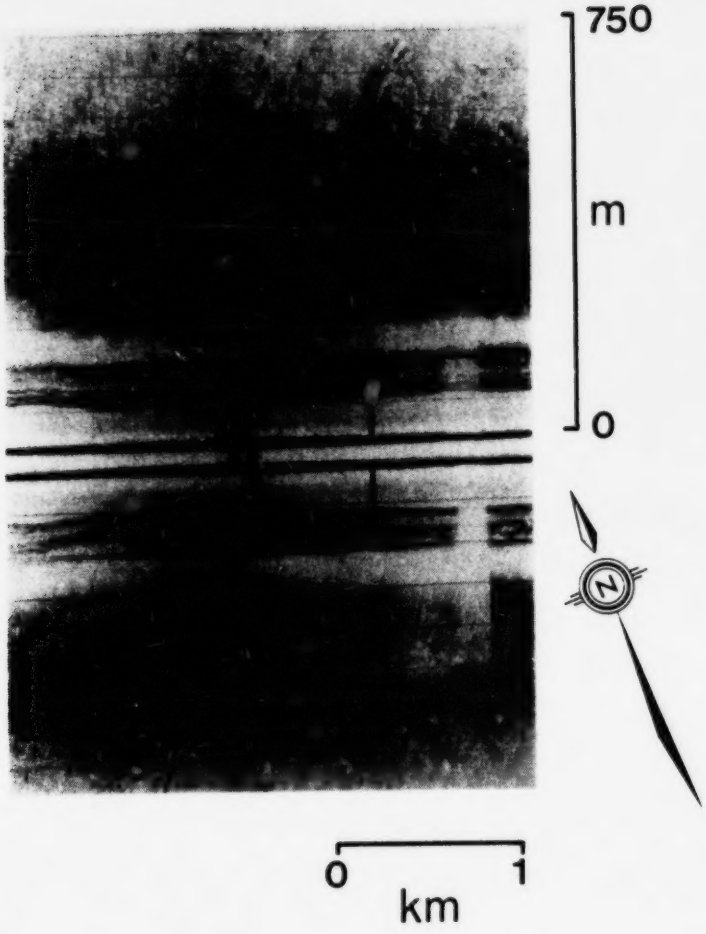

N

Figure 9 - Original sidescan record (distortion not removed) showing elliptical plan shape (dashed line) and smooth, unscoured flanks of the cone.


750
m
0
N
0
1
km

Interpretation

The cone is interpreted as a submarine mud volcano based on its morphology and structural position above the Cenozoic/Precambrian contact. However, several geomorphic features have conical and elliptical morphologies. Descriptions of the most common are presented below:

Thermokarst features such as pingos characteristically display asymmetric, conical morphologies and have been identified as submarine features in areas of the Beaufort Sea (Shearer et al., 1971). However, these can be ruled out because according to Shearer et al., (1971), the substrate in which they are developed must have been subaerially exposed prior to transgression. It was shown earlier that the study area was probably never emergent.

Drumlins are round to elongate hills which are formed subglacially. They have asymmetric flanks, the steep side generally facing the up-ice direction, and usually occur in groups or fields close to the position of maximum advance (e.g. Menzies, 1979). Similarly, drumlin can be ruled out because of the lack of evidence for glaciation of the sea floor in this area.

The fact that the cone has not been scoured by grounding icebergs whilst the adjacent seabed shows abundant scour marks, suggests the feature has been formed relatively recently. The presumed recent formation of the cone further argues against the cone being either a pingo or a drumlin which would be considerably older features.

Submarine slope failures are commonly related to crustal tectonics and earthquake shocks, excess pore water pressure and

possibly to gas-charged sediments (e.g. Prior and Coleman, 1979) and may develop on slopes with angles of less than one degree. Submarine sliding may affect extensive sheets of sediment ranging in thickness from 10 m in modern delta-front environments (Prior and Coleman, 1979) to over 360 m in basinal deposits (Moore et al., 1976). The surface morphology of slide deposits is quite variable, ranging from a few metres to kilometres. The seabed upslope of the cone is blanketed with 1 - 2 m of overburden above the Tertiary and Precambrian bedrock. It is unlikely that this is a sufficient thickness of sediment to initiate sliding on the regional slope, which is generally less than 0.5°.

Submarine landslides do not tend to produce discrete positive conical seabed features and there is no evidence of disturbed seabed material upslope of the cone that might indicate a possible landslide source. Neither is the cone likely to be an integral part of an aerially extensive landslide sheet because it is unscoured and therefore, as suggested earlier, younger than the scoured seabed which surrounds it.

It is possible that the gently east-dipping Tertiary strata in this region protrude through the thin veneer of surficial sediments to form a cuesta. However, the 3.2° eastern slope of the cone compared to the 0.5° dip of the Tertiary strata make this an unlikely explanation.

Recent tectonic activity in this area (Wetmiller and Forsyth, 1978) may have caused localized disruption of surficial sediments along a fault plane (or planes) which reaches the surface. However, fault movement would not produce a conical

surface feature although there is evidence to suggest the existence of a local, steep south-facing slope southeast of the cone (Figure 7).

Mud volcanoes may be defined as planoconical features up to 500 m high, with base diameters that maybe over 3 km. The cone material is comprised largely of pelitic sediments, usually containing rock fragments which may be associated with oil, gas and conate water (Kugler. 1938; Levorsen. 1954, Solovyev et al., 1961; Birchwood, 1965; Newton et al., 1980). Terrestrial mud volcanoes have been widely identified (O'Brien, 1968) and submarine mud volcanism and volcanoes have been reported from the Apsheron Peninsula and Bakinian Archipelago in the shallow parts of the Caspian Sea (Jakubov et al., 1971; Newton et al., 1980) and also from deep areas in the Caspian Sea (Solovyev et al., 1961). More recently, submarine mud volcanoes have been recognized between the Barbados Outer Ridge and Ridge Complex east of the Antilles Volcanic Arc (Stride, et al., 1982)

Terrestrial mud volcanoes are found on the coastal areas of Trinidad (Weeks, 1929, Birchwood, 1965; Higgins & Saunders, 1967) and in Burma (Chibber. 1934; Stamp, 1934), West Pakistan (Snead, 1964), Taiwan (Lin, 1965), Rumania, Italy, Iran, Iraq, New Zealand, India. Malaya, Java, Borneo, Venezuela, Colombia, Southern U.S.A., Gulf of Mexico and the Arakan coast (Jakubov et al., 1971). Newton et al., (1980) stated that submarine mud volcanoes which occur below wave base should have the same appearance and dimensions as terrestrial mud volcanoes but that dilution of the ejected material by seawater could reduce the

cohesiveness of the sediment and limit the height of the cone. Both terrestrial and submarine mud volcanoes are always found in association with structural features such as anticlines, faults and fractures, and with oil and gas deposits (Arkhanguelsky, 1925; Stamp, 1934; Snead, 1964; Birchwood, 1965; Freeman, 1968; Newton et al., 1980).

Kugler (1938) and Freeman (1968) described the process by which clastic rocks are extruded to the surface as "sedimentary volcanism". Freeman (1968) and Newton et al., (1980) noted that the driving mechanism for volcanism is the discharge of high pressure gas and/or water-charged mud. Extrusion of material can range from slow and non-violent (Snead, 1964; Birchwood, 1965) to violent eruptions, depending on the consistency of the pelitic material. Eruptions are triggered when confining pressure is released (Kugler, 1938; Levorsen, 1954; Snead, 1964; Higgins and Saunders, 1967; Freeman, 1968; Newton et al., 1980). This may be accomplished by movement along fault planes (earthquakes) or dilation of fissures (e.g. Freeman, 1968; Newton et al., 1980). Snead (1964) observed that 75% of all eruptions of mud volcanoes in Baluchistan were directly related to earthquakes. Because many mud volcanoes are associated with deep-seated faults (Freeman, 1968) the ejected material may contain clasts derived from rocks at great depth. Kugler (1938) noted that mud volcanoes from the Caucasus Mountains contain erratic blocks that have been brought up from depths as great as 6,100m.

CONCLUSIONS

It is concluded that the seabed feature in the study area is probably a mud volcano because it displays the following characteristic features:

i. It has a volcano-like conical morphology. The subdued nature of the cone is explained by dilution and immediate dispersion of the ejected material by seawater (Newton et al., 1980).

ii. A crater located on the cone may be the vent. As noted previously, the crater is located adjacent to the summit. The absence of a central vent is unusual but it may be that a central vent did exist but became inactive and was filled in by mass wasting processes or by ponding of fluid mud. The observed crater may represent a parasitic side vent. Secondary vents are common features on many volcanoes of igneous origin.

iii. The cone is elliptical in plan view with the long axis oriented parallel to the Precambrian/Tertiary contact below. The contact plane would provide an ideal conduit for the upward migration of pressurized, sediment-laden oil, gas and water, the agents which create mud volcanoes. It has been demonstrated by other workers that contacts between similar rocks offshore from Scott Inlet are known sites of gas and oil emissions.

iv. Earthquake activity has recently been observed in the vicinity of the study area and it is possible that periods of mud volcanism may accompany seismicity, as has been reported by Snead (1964) from Baluchistan.

v. Because the cone is smooth-sided and is on a seabed much

disturbed by iceberg scours, it is likely that the volcano is a recent feature.

Mud volcanoes have been reported from several localities worldwide and the associated engineering hazards have been noted (e.g. Newton et al., 1980). These hazards include the risks involved in laying pipelines across areas where mud volcanoes occur, and the effect on operations near dormant mud volcanoes where drilling may trigger eruptions or blowouts (e.g. Newton et al., 1980). Further work should be carried out along the regional Precambrian/Tertiary contact of Baffin Island in order to identify the hazard areas where other mud volcanoes or oil seeps may affect offshore hydrocarbon exploration and extraction activities.

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